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IREAPS

ECONOMIC BENEFITS AND TECHNOLOGY OF CU/NI SHIP HULL SHEATHING

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ABSTRACT

Fuel consumption of ships is related to hull roughness. The increasing high cost of fuel is the driving force behind the efforts that are expended in looking for methods which would reduce hull roughness and would maintain a smooth hull surface profile during the designed life of a ship. One such desirable method involves the use of copper-nickel.

This study examined a number of methodologies for applying Cu/Ni in sheet form. The welding of Cu/Ni clad steel was also evaluated in a shipyard environment. The cost differential between Cu/Ni sheathed and conventional painted hulls was determined for a large container ship.

The economic analysis was based on 1980 cost figures and a specific application method of Cu/Ni hull sheathing. The results were 33.5% for the effective discounted cash rate of return and 4.2 years for the zero-interest breakeven point, against an initial incremental investment of $3.4 million using 46% tax rate.

I. INTRODUCTION

The single most expensive aspect of operating a ship today is the cost of fuel (1). Effective energy-saving measures, in the context of the overall U. S. shipbuilding industry, would have a significant and favorable impact on the balance of payment of the Administration as well.

The fuel consumption of a conventional painted ship is strongly dependent upon the hull surface roughness. In this regard, the most important factors include the roughness of the paint, roughness induced by marine biofouling and erosion-corrosion of the steel plate. There are in the normal.state-of-the-art quite a few known methodologies for controlling - to varying degrees of success to be sure - the deterioration of materials or structures exposed to marine environments. They may be classified as barriers, inhibitors, inert materials, temperature and velocity controls. A common barrier type approach for ship hulls is the antifouling coating. These coatings owe their enhanced biofouling resistance to the presence of cuprous oxide and tributyl tin oxide. Many copper-base alloys exhibit varying degrees of resistance to biofouling (2). Copper alloy CA-706 is reported to have excellent erosion-corrosion as well as antifouling properties proven by several engineering structures used in different environments (2-7). The composition of CA-706 is given in Table 1.

Based on extensive economic and technological assessments of how to build large composite ship hull structures, the two most promising avenues looked to be sheathing and cladding (8-9).

Sheathing may be defined as the use of Cu/Ni alloy sheet which is bonded in situ to steel plates already erected as ship hulls or ship modules. Cladding can be defined as a bimetallic material composed of a carbon steel substrate to which, on one side only, a layer of Cu/Ni alloy is already metallurgically bonded when received for construction.

TABLE I

Chemical Composition of Alloy CA-706

(Values given in weight percent)

Cu	Ni	Fe	Mn	Pb	P	S	C
88.6	9.0-11.0	1.0-1.8	1.0 max	.02 max	.02 max	.02 max	.05 max

While prior studies on cladding indicated technological feasibility it was found to have certain disadvantages relative to the sheathing approach. These drawbacks include higher purchase price, composite plate size limitation, and its use largely limited to new or special constructions. Sheathing, on the other hand, is much more versatile in that it lends itself to retrofit, new construction, and easier automation. Furthermore, the initial purchase price of sheathing is considerably lower.

II. PROCEDURE

Two state-of-the-art application methods considered for sheathing a steel hull were:

1. 100% peripheral (seam, butt or fillet) weld,
2. 100% peripheral weld plus slot weld.

In the initial laboratory phase small Cu/Ni test coupons of 3" x 6" x .10" (76.2 x 152.4 x 2.5 mm) size were used on ABS Grade B steel samples of 10" x 16" x .75" (254 x 406.4 x 19 mm) dimension. The size of the clad sample was 4" x 12" x 1" (101.6 x 304.8 x 25.4 mm). In the final laboratory phase only the sheathing method was tested using sample sizes of 3' x 5' x .10" (91.44 cm x 152.4 cm x 2.5 mm) for the Cu/Ni and 7' x 12' x .4375" (213.4 cm x 365.8 cm x 11.1 mm) for the steel plate.

On every steel sample three Cu/Ni coupons or panels were welded to duplicate the sheathing arrangement on the ship hull. A schematic drawing of the arrangement is shown in Figure 1. The graphical illustration of the clad sample and the sequence of its welding can be seen in Figure 2.

Of the fusion arc welding processes, the shielded metal-arc and the gas metal-arc welding were chosen. Both weld methods were evaluated in all welding positions. The respective weld data can be found in Table II.

III.A. WELDING OF CU/NI SHEATHS TO STEEL PLATES

(a) Gas Metal-Arc Welding

The increase in weld productivity is an important factor in safeguarding the future of any shipyard. With that in mind, the gas metal-arc welding (MIG) was first evaluated for welding Cu/Ni-Fe/C dissimilar materials. The list of parameters investigated with MIG is given below.

* Gap sizes of .125", .250", .375" and .500" (3.2-12.7 mm) between adjacent Cu/Ni panels,
* Low, normal and high weld heat input,
* Typical rust on steel, clean to "white metal" and shotblast-and-preproduction zinc rich primed steel surface,
* Flat, horizontal, vertical down and overhead weld positions,
* Peripheral weld,
* Peripheral weld plus slot weld
* Argon/Helium (75/25%) and pure Argon (100%) shielding gas.

Factors held constant were as follows:

* Monel 60 (ASW A5.14 Class ER NiCu-7) filler metal,
* Weld wire diameter .035",
* Shielding gas flow rate @ 12.5 ft^3/hr,
* Direct durrent reverse polarity (DCRP).

TABLE II

Some of the Principal Welding Data Used in the Final Laboratory Phase

Welding Process	Welding Current (Amps)	Voltage (Volts)	Current Type and Polarity	Filler Metal		Shielding		Pre-Heat	Post-Heat
				Type	Size	Gas	Flow Rate (ft^3/hr)		
SMAW	80, F*	-	DCRP	ENiCu-2	3/32"	-	-	None	None
	80, H*	-	DCRP	ENiCu-2	3/32"	-	-	None	None
	75-80, VU*	-	DCRP	ENiCu-2	3/32"	-	-	None	None
	75, OH*	-	DCRP	ENiCu-2	3/32"	-	-	None	None
MIG (1)	230, F*	24	DCRP	ERNiCu-7	.035"	100% Ar	12.5	None	None
	230, H*	24	DCRP	ERNiCu-7	.035"	100% Ar	12.5	None	None
	230, VD*	24	DCRP	ERNiCu-7	.035"	100% Ar	12.5	None	None
	180, OH*	22	DCRP	ERNiCu-7	.035"	100% Ar	12.5	None	None

*F - Flat Position
H - Horizontal Position
VU - Vertical Up Position
VD - Vertical Down Position
OH - Overhead Position

(1) Welding currents indicated pertain to "Normal Heat Input" conditions (@ wire speed of 8 ipm for F, H, VD, and @ 6.4 ipm for OH)

Note: The maximum allowable interpass temperature for SMAW: in OH 200°F
VU 350°F
H & F not important (to make good welds)

Penetration of the weld into the steel substrate was found to be a function of the amount of rust present on the steel, the size (width) of the gap between adjacent Cu/Ni sheaths and the weld heat input, all else being constant. Figure 3 shows the gap size plotted against the width of weld penetration. The graph also indicates the percentile lack of penetration (LOP).

The magnitude of the crack-like discontinuity (CLD) present at the intersection of the copper/nickel-steel-Monel weld is very much influenced by:

1. Gap size
2. Steel surface condition with respect to rust
3. Fit up of Cu/Ni on Fe/C

Imposition of hydrodynamic conditions on hull weldments provide a preference for a weld profile flush with the Cu/Ni sheets.

In the liquid state, the surface tension of Monel 60 weld wire and the inferior wetting conditions of the weld joint made it impossible to obtain a smooth, flush weld profile. In the flat, the horizontal and the overhead positions the weld had a very pronounced reinforcement and in the vertical down position a concave configuration. Single pass welds in small gaps produced too 'much LOP and unsatisfactory weld shape in all weld positions regardless of weld heat input.

While some sporadic spatter and minute surface porosity occurred with MIG welding, their occasional presence is not viewed with concern. In terms of minimal LOP, the optimum gap size seems to be .5" (12.7mm). The ideal sequence of weld passes to fill such a gap is to perform two fillet welds - one on each side of the joint - and one fill-in pass. This weld practice hereinafter shall be referred to as "2f+f-i" and is highly advisable in all weld positions. The fillet welds are to ensure adequate "nailing' of the copper/nickel panels to the underlaying steel hull plate. The fill-in pass serves primarily as a 'leakproof" and profile satisfying weld pass. Figure 4 shows the "2f+f-i" weld sequences, graphically.

The role of interpass temperature with Monel 60 MIG welding is extremely important: in overhead weld position the most critical. No acceptable weld could be made in OH position irrespective of heat setting, travel_.speed and substrate temperature. The preproduction zinc rich primer coating had no detrimental effects upon the weld quality.

(b) <u>ShIelded Metal-Arc Weldiug</u>

Perhaps the most widely recognized merit of the shielded metal-arc (SMA) welding is that joints which are reachable with an electrode of the proper diameter can be welded in virtually any position. In welding hulls of large ships such an attribute has a special significance. The SMA process, on the other hand, has one notable shortcoming; i.e., low productivity.

The approach to SMA welding of Cu/Ni-Fe/C composites was similar to that used in MIG. The parameters investigated included:

* Gap sizes: .125", .250", .375", .500", ,625"
* Interpass temperature
* All weld positions
* Peripheral weld
* Peripheral weld plus slot weld
* Rusted Steel
* Rust-free steel

Monel 190 (AWS A5.11 Class ENiCu-2) electrode size 3/32" (2.38 mm) and DCRP were used in the SMA experiments. The "2f+f-i" weld sequence was utilized as in the MIG evaluation tests.

Requirements for rust removal, mitigation of CLD are governed by the same considerations elucidated in conjunction with MIG welding. Again, the presence of preproduction zinc-rich primer posed no problem. Table III portrays SMAW requirements. Figure 5-6 show the action and the result of shielded metal-arc welding of Cu/Ni-Fe/C ship hull composite material.

TABLE III

SMAW Requirements for Optimum Results in Specific Weld Positions

Weld Position	Welding: Current (amps) "2f"	Welding: Current (amps) "f-i"	Welding: Type	Welding: Polarity	Electrode: Type	Electrode: Size (in) "2f"	Electrode: Size (in) "f-i"	Interpass Temperature (°F)	Gap Size Between Cu/Ni Panels (in)
F	80	120	DC	R	Monel 190	3/32	1/8	*	3/8
H	80	120	DC	R	Monel 190	3/32	1/8	*	3/8
VU	75-80	90-120	DC	R	Monel 190	3/32	1/8	350 max.	5/8
OH	75	75	DC	R	Monel 190	3/32	3/32	200 max.	3/8

*Not important from the standpoint of making a sound weld.

NOTE: (a) Voltage was not measured. Used OC setting.

(b) Weld current for slot welding should be 5 amps higher than that of corresponding weld positions for peripheral welds.

III.B. WELDING OF CU/NI CLAD STEEL PLATES

(a) Shielded Metal-Arc Welding;

The practice of welding Cu/Ni clad steel in essence consists of a two-step approach. First, the steel side root pass is welded by E6010, size 5/32" (3.97mm), DCRP. The joint preparation on the steel side involved single "V" with 60° included angle and 1/16"-1/4" (1.59-6.35mm) land. The purpose of the land is to prevent dilution. The root opening ranged from zero (0) to 1/8" (3.18 mm) in increments of 1/16" (1.59 mm).

In welding the clad side, two different joint preparation procedures were evaluated.

(1) Groove or joint preparation by means of air carbon-arc with carbon rod diameters of 3/16" (4.76 mm) and 5/16" (7.94 mm) so as to determine the minimum groove size necessary to insure acceptable weld quality using Monel 190, size 3/32" (2.38 mm) electrode. Back-gouging was extended into the root pass of the steel side welds to remove entrapped slag inclusions.

(2) Backstripping of the Cu/Ni cladding up to 3/8" (9.53 mm).on both sides of the joint. Backgouging of the steel root pass and welding were along the lines outlined above. The 1/8" (3.18 mm) root opening is preferred to the tight root (or nose), especially with the back-stripping method. The root opening of this magnitude requires less time to backgouge, causes less slag entrapment and provides an easier access to the making of the steel side root pass. The welding current for E6010, size 3/16" and E6027, size 5/32" was 130 amps, DCRP. The clad side welding current ranged from 85-90 amps, DCRP.

IV. STRUCTURAL INTEGRITY ASSESSMENTS

The mechanical and metallurgical characterization of copper/nickel-steel composite material is essential to the prediction of its behavior in service. Today, a limited applied engineering knowledge exists about the elastic and plastic behavior of this composite assessed under either laboratory or field conditions. This is particularly true for hull applications of large surface vessels.

(a) Metallurgical Investigations

The base steel had a ferrite-pearlite microstructure characteristic of a carbon-manganese steel (ABS Grade B). In going through the respective heat affected zones the microstructures and the grain sizes changed under the influence of the weld heat input due to a temperature gradient. At the weld metal-steel interface, there was some evidence of copper "fingers" running down the austenite grain boundaries. Microcracks and crack-like discontinuities were on occasion noted in this region. The copper/nickel HAZ showed a fine dendritic microstructure changing to selective melting along the grain boundaries of the base copper/nickel. The Monel 190 weld displayed a coarse dendritic microstructure. The base copper/nickel exhibited a recrystallized grain structure with evidence of twinning and alloy segregation.

As expected, hardness measurements traversing the base metals, the HAZ's and the weld illustrated a change in hardness values. The relative hardness values are indicative of the changes in the microstructure.

(b) Mechanical Testing

To gain some insight into the behavior of Cu/Ni-Fe/C composite weldments under static and dynamic loading conditions a few small samples were tested at ambient temperature. The static tests involved tensile testing of the base copper/nickel and lap shear testing of butt and slot welds. The dynamic tests consisted of low-cycle fatigue of the tension-compression (alternating stress) and pulsating (tension-tension) mode.

The mechanical properties of the base copper/nickel agreed with published values for the annealed ("0" temper) condition. Due to geometric effects (stress concentrations) and residual stresses, the ultimate tensile strength of the copper/nickel at the weld is less than that of the non-welded Cu/Ni, but is above the yield strength of the base Cu/Ni. The lap shear stress of both the butt and the slot welds is greater than the ultimate tensile strength of the base Cu/Ni alloy. In other words, failure under overload conditions should normally occur in the Cu/Ni HAZ, as in fact it did. Fatigue failure also occurred in the Cu/Ni HAZ starting at the crack-like discontinuity (CLD). CLD is formed by the inherent geometry of the steel substrate, the copper/nickel panel and the Monel 190 weld joining the dissimilar metals together. A stress concentration is always inherent in such configurations. One fatigue test sample failed in the base steel at some gross weld discontinuity. This suggests the need to examine the significance of weld discontinuities leading to the establishment of weld acceptance standards.

V. ECONOMICS

Like everything else, the ultimate viability of the Cu/Ni ship hull sheathing as a concept is measured by its economics. On one side of the economic balance is the initial investment (see Figure 7); while savings on the other (Figure 8). The elements of savings may conveniently be categorized as major, minor and miscellaneous. The major elements of savings for ship owner/operators come from lower fuel consumption, decreased dry docking, reduction in shaft horsepower requirements and propulsion plant size.

In the past, the cost of fuel, dry dock refurbishing methods and other attendant losses were relatively low. Hence, the cost differential between conventional, painted steel hull and clad or sheathed steel hull mitigated against the application of copper/nickel.

In the 1970's, notably in 1973 and 1979, the price of crude oil suddenly escalated so much so that today the single biggest expense in operating large ships is tied up in fuel. Reportedly, fifty percent of the total cash flow for ship owner/operators is associated with fuel consumption. This and the heightened inflation worldwide hurled the Cu/Ni concept into prominence as an attractive economic counter-measure.

In the minor savings category are increased profit, reduction in revenue losses, and scrap value of Cu/Ni at the end of the useful life of a ship. A list of miscellaneous savings considerations may consist of larger cargo capacity arising from a reduction in propulsion plant size, investment tax credit potential through governmental policies, increase in ship speed due to a smoother hull surface.

It is fair to state that a precise economic assessment and forecast can at best be approached if the exercise of economic modelling is tailored to a specific ship scenario. So, our economic analysis took the approach of selecting a container ship with its engineering specifics, sea-going environments and assumed annual operating days as shown in Figures 9 and 10.

The initial investment of Cu/Ni sheathing was based on modular construction using a combination of SMA peripheral and slot welding attachment methods and a 10% profit. This approach gave rise to an estimated cost differential between conventional coating and sheathing of $3.4 million. Further conservative assumptions included 2 mils for the roughness of sheaths remaining constant and precluding biofouling for the life of the sheathed vessel. A conventional painted steel hull has an inital roughness of about 5 mils MAA (Mean Apparent Amplitude). With a typical hull maintenance of sand brushing and recoating on a biennial schedule, the hull surface continues to degrade with time at an assumed rate of 1 mil per year. In addition , fouling has to be reckoned with so far as conventional painted steel hulls are concerned. For that, 1 mil of roughness per year was used in the economic calculations. Both the conventional and the composite ship were taken to operate at the same speed over the 20 year assumed operational life of the respective ships.

Several authors (10-14) studied the effect of hull roughness on changes in power requirements. A plot of increasing power requirement as a function of years-in-service after Professor Benford (10) is given in Figure 11. An empirical relationship between increasing shaft horsepower and hull roughness differential between a painted hull and sheathed hull proposed by Townsin (11) is also shown 'in Figure 11. The so-called "saw tooth effect" of the power vs years-in-service graph is the result of periodic hull cleaning of conventional painted steel hulls.

The 1980 cost of bunker "C" fuel was taken at $21.00 per barrel representing U.S. oil price. It is worth pointing out that the international price of crude is substantially higher than that of domestic oil ($32-35/bbl as of June 1980). Fuel, dry docking and scrap value of Cu/Ni were escalated at an annual rate of 10% over the life of the Cu/Ni sheathed vessel. The computer input data are illustrated in Figure 12.

For an effective discounted cash rate of return and zero-interest break-even point, 33.45% and 4.22 years after the start of ship construction (i.e., 1 year construction + 20 year ship life = 21 years) were obtained, respectively.

There are several additional benefits that may be derived from Cu/Ni sheathed ships. The present economic model assigns no credit to the real possibility for an appreciably longer useful life for the Cu/Ni sheathed ships than their conventional counterparts. Finally, favorable governmental policy through such measures as investment tax credit should pave the way for still another advantage to be realized with Cu/Ni by,U.S. ship owner/operators. As for the Cu/Ni clad steel, the high material cost still negates its application for large ship hulls based on 1980 domestic oil price. However, it is economical for special constructions.

VI. CONCLUSION

(*a) Sheathing

Of the many possible application techniques, two of the more common fusion-arc welding methods were examined.

Copper/Nickel can be welded to commercial ship hull steel satisfactorily in all weld positions by the shielded metal-arc welding process. The preferred weld pass sequence consists of two fillet welds and fill-in pass(es). This "2f+f-i" weld practice ensures the welding of the Cu/Ni panels to the steel substrate and helps provide a leak-proof weld as well as a flush weld profile. The surface appearance of the weld in terms of profile was best when Monel 190 electrode size 3/32" for "2f" and l/8" for "f-i" was used in F, H, and VU positions. In the OH position, the l/8" size electrode was found too large.

The gas metal-arc welding using Monel 60 size .035' solid wire electrode gave unsatisfactory results notably in out-of-position welds. In F and H positions, the weld had an excessive reinforcement. The weld profile showed too much concavity in VD position, while in OH position no acceptable weld could be made continously due to fluidity problems of the filler metal. The interpass temperature in out-of-position welding with GMAW in particular was found to be extremely important. The maximum interpass temperature in OH and VU should not exceed 200°F and 350°F, respectively.

The presence of preproduction primer coating posed no problem in either SMA or GMA welding of Cu/Ni-Fe/C composite.

A brief mechanical characterization of Cu/Ni-Fe/C weldment showed under low cycle loading conditions that fatigue crack propagation would normally occur in the HAZ of Cu/Ni sheath, initiated at an inherent crack-like discontinuity being at the Copper/Nickel - Steel - Monel interface.

An economic analysis of Cu/Ni sheathing of hulls of large commercial ships produced very attractive results. Against an initial incremental investment of $3.4 million and using 46% tax rate, the effective discounted cash rate of return and the zero-interest breakeven point were calculated to be 33.5% and 4.2 years, respectively.

(b) Cladding

There are two common ways of preparing the weld joint in clad steel: (1) groove the steel side with 1/16-1/8" land in the steel to prevent dilution, arc-air the groove on the clad side or (2) groove the steel side to the steel-cladding interface and backstrip the cladding. In either case, a 1/8" root opening minimizes slag entrapment and backgouging.

Irrespective of joint preparation methodologies selected, the actual welding sequence of Cu/Ni clad steel is as follows. Weld the steel side with the appropriate steel filler metal first (in our case: E6010 and E6027), backgouge the steel root pass prior to welding the Cu/Ni clad side with Monel 190 filler metal.

While the Cu/Ni clad steel for ship hulls is not as economical as the sheathing method, the Cu/Ni clad steel is cost-effective for special requirements.

VII. RECOMMENDATION

In view of the favorable technological and economic results, recommendations were made to test the copper/nickel sheathing and cladding methodology on a commercial ship in an actual ocean-going environment. Figure 13 shows the installations of copper/nickel on a fast (26 knots) container ship (DWT: 29,896 metric tons).

REFERENCES

1. O'Brien, L. J., Congressional Information Bureau, Vol. 84, No. 75, April' 17, 1980, p. 11.

2. "Marine Biofouling", INCO, 6M 9-79 5719(5), New York, New York, U.S.A

3. Fu, J., "Results of Cu/Ni Erosion-Corrosion Experiments on GREAT LAND and WESTWARD VENTURE", Sun Ship Report, 1977.

4. Manzolillo, J. L., et al, "CA-706 Copper-Nickel Alloy Hulls: The Copper Mariner's Experience and Economics'-', SNAME No. 3, 1976.

5. 'Copper-Nickel Hull Cladding Cuts Maintenance and Fuel Costs', Metal Construction, The Journal of The Welding Institute, Vol. 11, No. 4, April, 1979.

6. Bicicchi, R. T., et al, "Hull Experiments on 24 Knot RO/RO Vessels Directed Toward Fuel-Savings Application of Copper-Nickel"SNAME Annual Meeting, Paper No. 9, 1978.

7. Thiele, E. W., Jr., et al, "Fabrication of Copper-Nickel Systems for Antifouling and Maintenance-Free Applications", OTC Paper No. 1960, 1974.

8. Sandor, L. W., "Cost Calculations of Roll Bonded Cu/Ni Clad Steel Weldments", Unpublished Report #43-26-77-7, Sun Ship, Inc., September 23, 1977.

9. Sandor, L. W., "Costing the Sheathing Method", Unpublished Report #43-26-77-8, Sun Ship, Inc., September 28, 1977.

10. Benford, H., et al, "The Prediction of Hull Roughness and Its Use in an Economic Study of Cu/Ni Hull Applications vs. Conventional Steel Hulls', Unpublished Report, University of Michigan, December 15, 1978.

11. Townsin, et al, "Speed, Power and Roughness: The Economics of Outer Bottom Maintenance", Paper given @ RINA Spring Meeting, 1980.

12. Muntjewerf, et al, "Hull Deterioration and Fouling", Report, Appendix 7, Proceedings of 14th International Towing Tank Conference, 1975.

13. Hamlin, N., "Some Practical Considerations in Reducing Required Power for Ships", National Maritime Research Center, Kings Point, N.Y., Report NMRC KP-161.

14. Skepteknisk Forsknings Institutt,: (The Ship Research Institute of Norway), "Roughness Grades for Ship's Hulls", 1972. (Available BSRA translation: Bl90.)

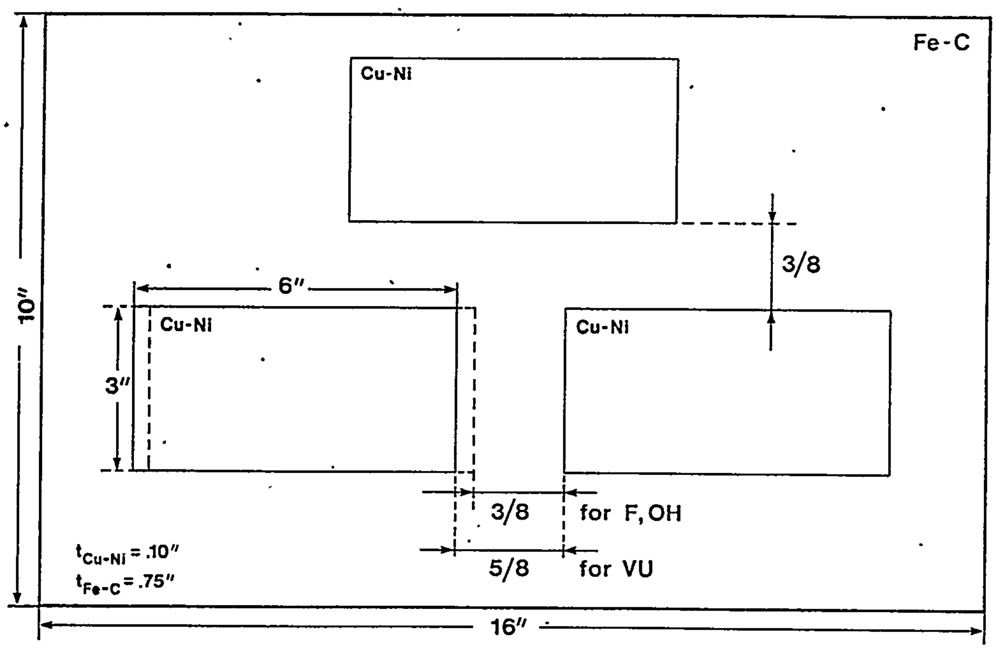

Fig. 1 - Scheme of Arrangement of Cu/Ni sheaths on steel.

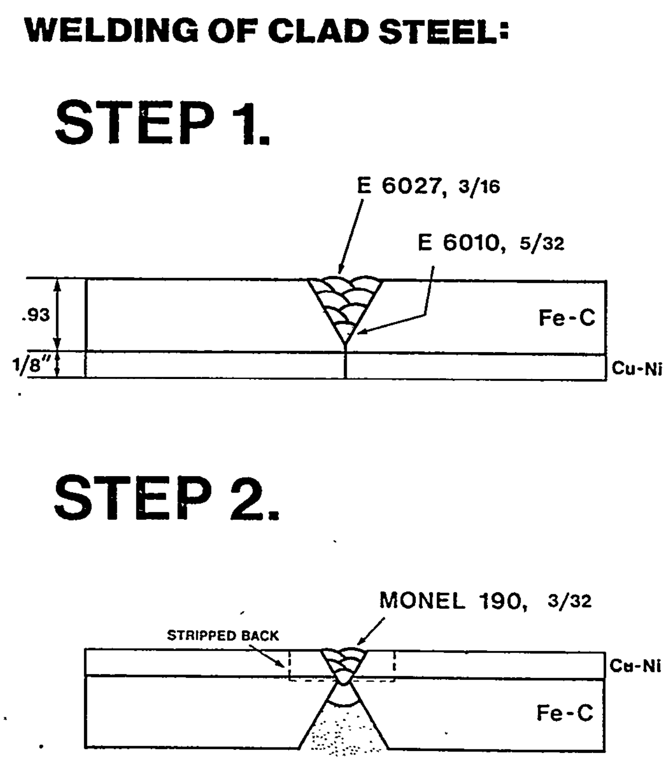

Fig. 2 - Graphical illustration of the welding of Cu/Ni clad steel.

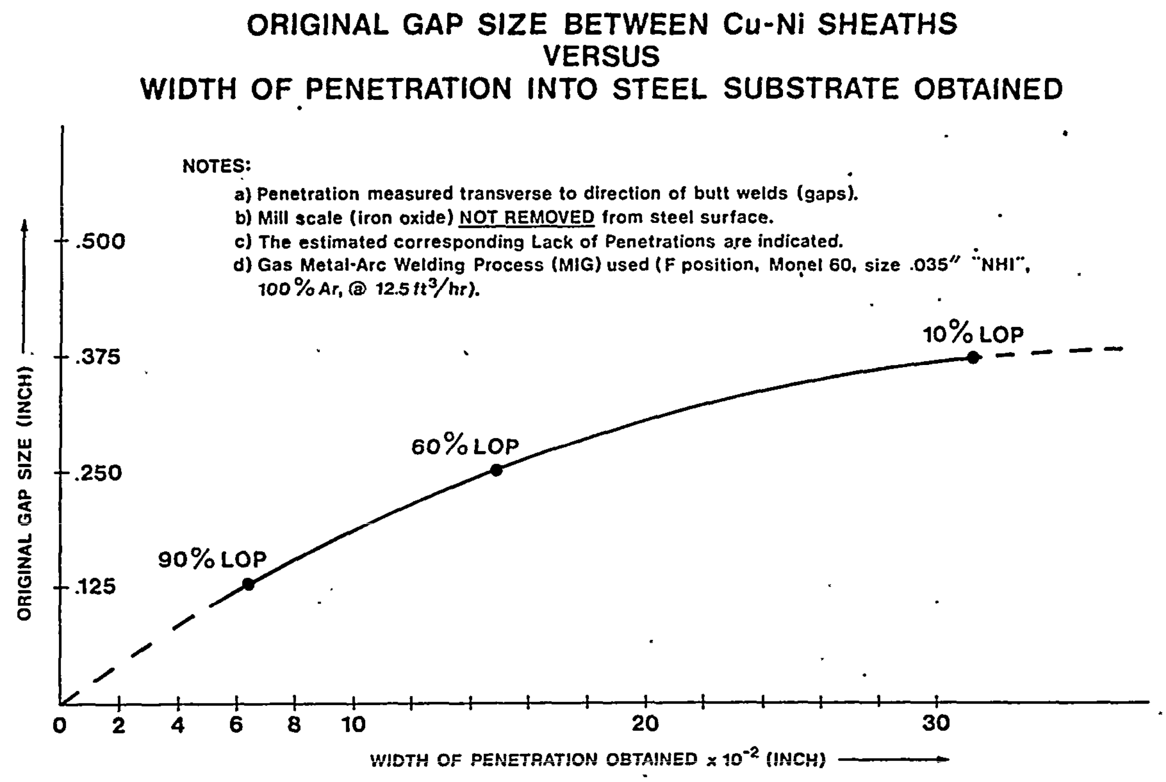

Fig. 3- Plot of gap size versus width of weld penetration into the steel substrate for constant "Normal Heat Input" and travel speed conditions.

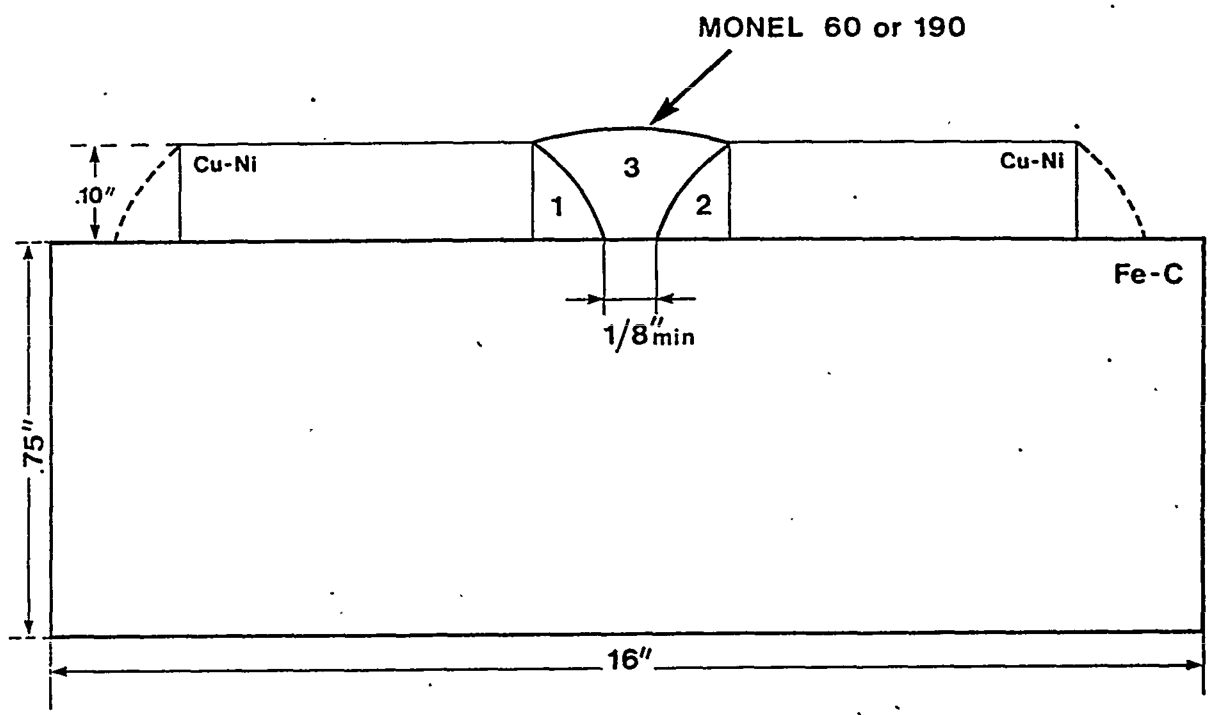

Fig. 4- "Fillet welds and fill-in pass" methodology for welding Cu/Ni sheaths to the underlaying steel hull plate.

Fig. 5 Peripherol welding in the vertical-up position using SWAW.

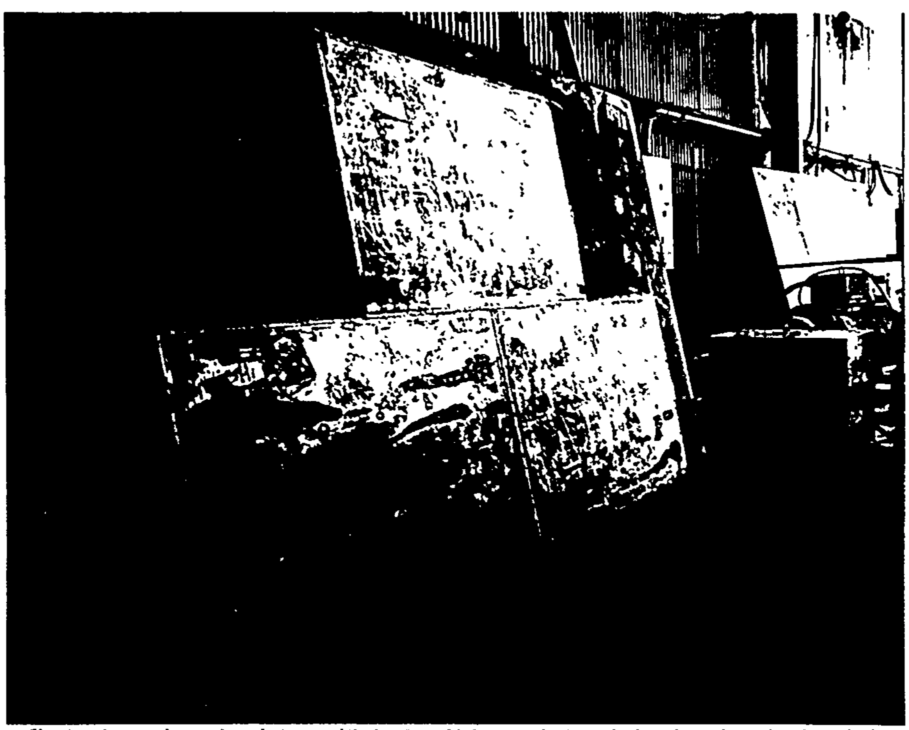

Fig. 6 A general overview of three Cu/Ni sheaths welded to a primed steel plate in horizontal and vertical (butt weld between the two sheaths on the bottom and fillet welds on the ends of each sheath) position.

INITIAL COST ELEMENTS

(A) CONVENTIONAL. PAINTED HULL	(B) Cu-Ni SHEATHED HULL
A.1 shotblasting + material	B.I sheathing material
A.2 painting + material	B.2 welding
A.3 add'l. staging for A 1 & A 2	B.3 grinding all welds
A.4 labor rates for A.I-A.3	B.4 fitting & tacking
A.5 drydock & services	B.5 setting-up work area
A.6 incidentals	B.6 construction services
	B.7 engineering
	B.8 iOO%NDT
	B.9 punching slots and/or adhesive(s)
	B.10 profit (10%)
-TOTAL = S.4 Million	$3.6 - 3.9 Million

$\Delta\overline{AB}$ = $3.4 M (average)

Fig. 7 Inltlal cost elements.

MAJOR ELEMENTS of SAVINGS

CONSIDERED for Cu-Ni

1. FUEL
2. **REDUCED DRY-DOCKING** (Biennial & Quadrennial)
3. ADDITIONAL REVENUE and PROFIT
4. PROPULSION PLANT REDUCTION
5. SCRAP VALUE of Cu-Ni

	PURCHASE	SCRAP
Cu-Ni PRICE:	$2.6946 per lb.	S1.17 per lb. (minus labor)$_{50}$yo

ESTIMATED SAVINGS DUE TO 2. & 3. above

BIENNIAL	QUADRENNIAL
$136,000	$103,000

Fig. 8 Major elements of savings.

ECONOMIC ASSESSMENTS

NEW CONSTRUCTION

e.g.: Hull # 678 (container ship)

677’LBP 95’ BEAM 54’ DEPTH

23knots @ 29.5’ Draft 26,352 DWT

.4849 Ib/SHP-HR @ Max. Power

30,000 SHP (108 RPM)
1,065 barrels/day

Bunker"C" $21.00/barrel
(U.S.A. price, March 1980)

(international price is higher)

79,000 ft^2 WETTED SURFACE

Fig. 9 Engineering specifics of a container ship used in the economicassessments.

INFLATION ESCALATOR (over 21 years): 10%

ANNUAL OPERATING DAYS: 300

ANNUAL FUEL CONSUMPTION: $6.0 Million @ 87 % rated SHP

INCREMENTAL POWER REOUIREMENTS

(Due to roughening of painted HULLS)

YEAR	$\dot{k}_p$ [mils]	$\Delta \dot{P}/\dot{P}$ [%]
1	6	9.5
2	8	12.6
3	8	12.6
4	10	15.2
5	10	15.2
6	12	17.5
7	12	17.5
8	14	19.5
9	14	19.5
10	16	21.4
11	16	21.4
12	18	23.1
13	18	23.1
14	20	24.7
15	20	24.7
16	22	26.2
17	22	26.2
18	24	27.6
19	24	27.6
20	26	28.9

Fig. 10 Additional factors taken into account of the Cu/Ni hull sheathing economics.

• Average (MAA) = initial + deterioration + fouling

•• Ref.: Townsin's paper; $100 \frac{\Delta P}{P} = 580 \left[(k_p)^{1/3} - (k_{CN})^{1/3} \right]$

where,

$100 \frac{\Delta P}{P} =$ required increase in SHP due to increasing roughness of' painted hull [%I

$k_P =$ surface roughness of painted hull [MAA meters = MAA mils x 25 x 10^{-6}]

$k_{CN} =$ surface roughness of Cu-Ni taken CONSTANT = 2 mils .

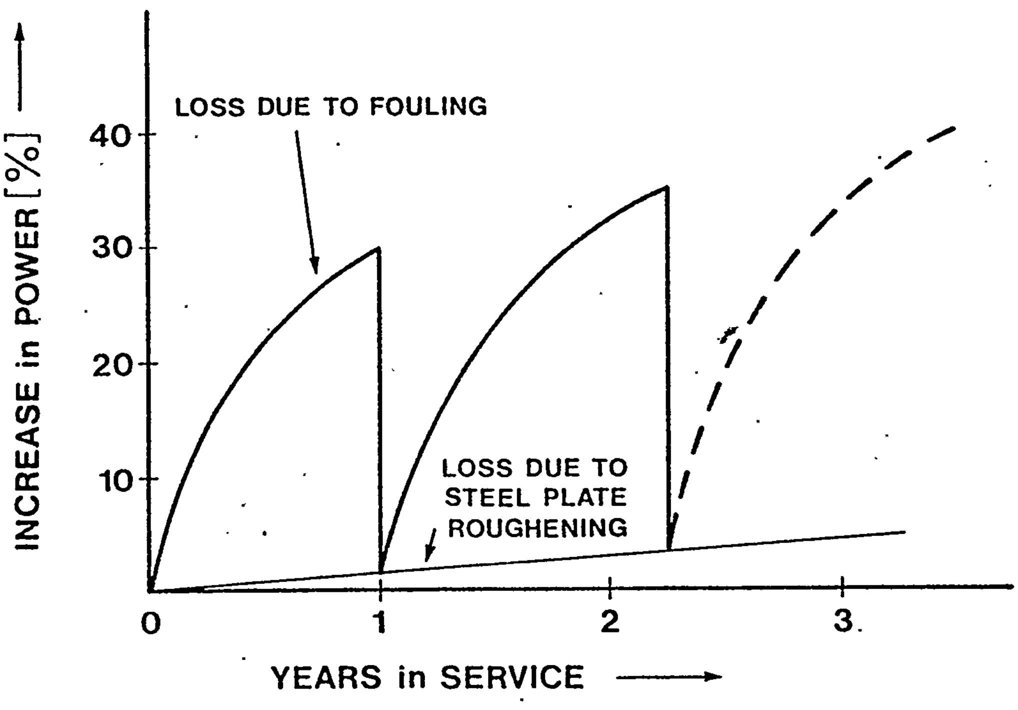

Fig. 11 Consequences of hull roughness due to fouling and base steel roughening with time on the shafthorsepower requirement.

COMPUTER INPUT DATA

CONSTRUCTION YEAR 1980

No. of YEARS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	TOTAL SAVINGS ($ Million)
FUEL	—	.658	.959	1.055	1.400	1.540	1.951	2.146	2.630	2.893	3.493	3.842	4.562	5.018	5.903	6.493	7.576	8.333	9.657	10.622	12.235	92.966
DD and REVENUE	—	—	.173	—	.158	—	.253	—	.232	—	.370	—	.339	—	.542	—	496	—	.793	—	727	4.083
12 % PP REDUCTION	400																					.400
Cu-Ni SCRAP																					1475	1.475
TOTAL SAVINGS	.400	.658	1.132	1.055	1.558	1.540	2.204	2.146	2.862	2.893	3.863	3.842	4.901	5.018	6.445	6.493	8.072	8.333	10.45	10.622	12.962 + 1.475	98.924

w/ INITIAL INVESTMENT: $3.4 Million & 46% Tax Rate

COMPUTER RESULTS:
ZERO-INTEREST BREAKEVEN POINT: 5.22 years or 4.22 yrs. FROM START-UP

EFFECTIVE DCRR: 33.45%

Fig. 12 Computer input data showing the results of economic analysis conducted.

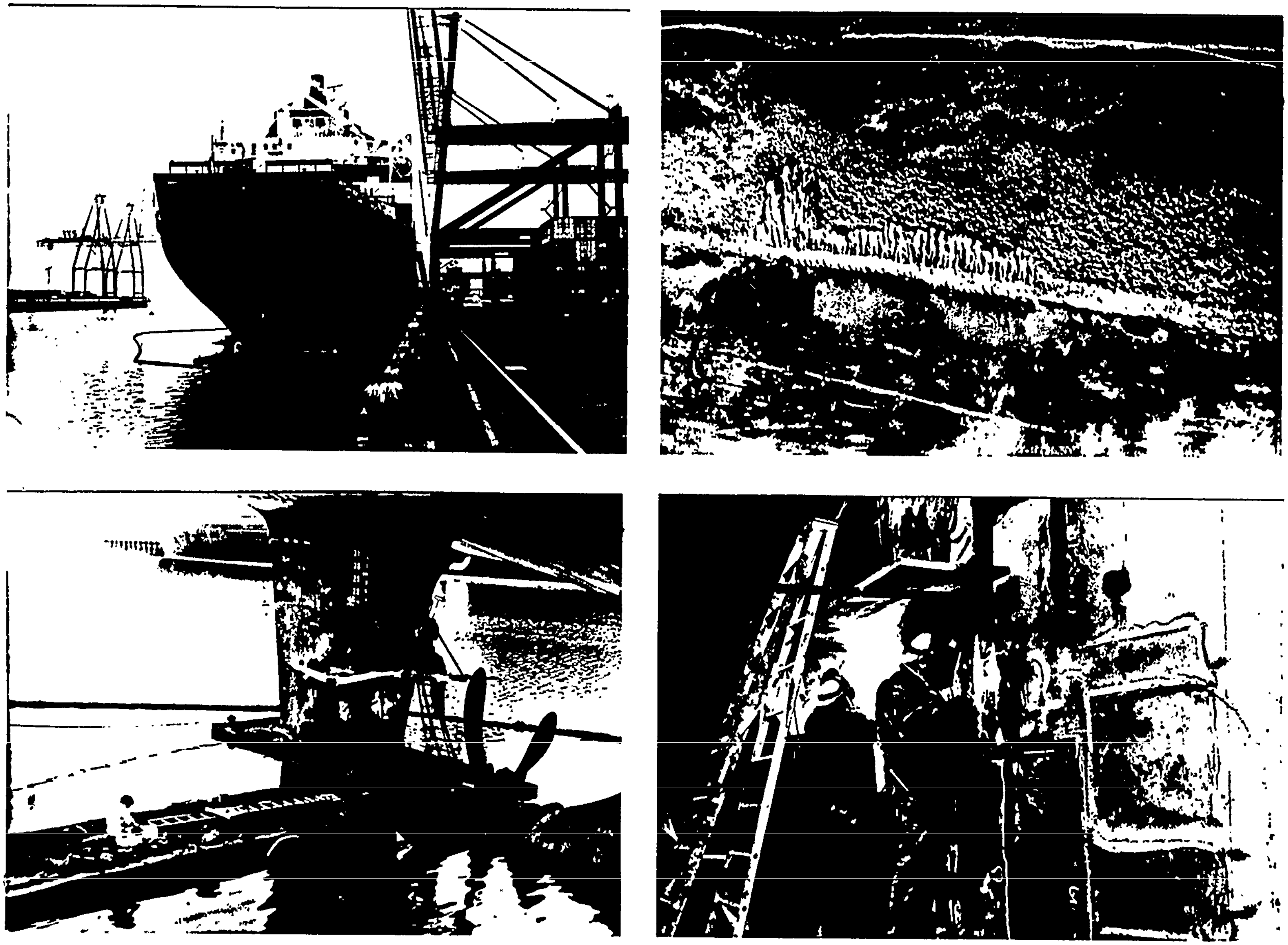

Figure 13. Installing copper/nickel on a fast (26 knots) container ship.

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